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CONTACT ELECTRIFICATION AND THE ELECTRIC CURRENT

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IN a previous paper in this journal, entitled "The Discovery of Contact Electrification" (November, 1913), it was shown that the production of electric charges by the mere contact of two dissimilar metals was first discovered by Rev. Abraham Bennett, in 1789, and that it was verified by a different method by Tiberius Cavallo, in 1795. Meantime, in 1791, Dr. Galvani discovered the twitching of a frog's muscle, due to electrical stimulus. Galvani's discovery was described by himself as follows:¹

I had dissected a frog and had prepared it, as in Figure 2 of the fifth plate, and had placed it upon a table on which there was an electric machine, while I set about doing certain other things. The frog was entirely separated from the conductor of the machine, and indeed was at no small distance away from it. While one of those who were assisting me touched lightly and by chance the point of his scalpel to the internal crural nerves of the frog, suddenly all the muscles of its limbs were seen to be so contracted that they seemed to have fallen into tonic convulsions. Another of my assistants, who was making ready to take up certain experiments in electricity with me, seemed to notice that this happened only at the moment when a spark came from the conductor of the machine. He was struck by the novelty of the phenomenon, and immediately spoke to me about it, for I was at the moment occupied with other things and mentally preoccupied. I was at once tempted to repeat the experiment, so as to make clear whatever might be obscure in it. For this purpose I took up the scalpel and moved its point close to one or the other of the crural nerves of the frog, while at the same time one of my assistants elicited sparks from the electric machine. The phenomenon happened exactly as before. Strong contractions took place in every muscle of the limb, and at the very moment when the sparks appeared, the animal was seized as it were with tetanus.

Following this original observation, Galvani made a great many experiments on the effect of electric stimulus upon the nerves of frogs and other animals. He found that the twitching of the frog's muscles could be produced by atmospheric electricity, both at the time of lightning and at other times when no lightning was visible. During these investigations he observed that when the legs of the frog were suspended from an iron railing by a hook through the spinal cord, and when this hook was of some other metal than iron, the muscles would twitch whenever the feet touched the iron railing. He tried out a

¹ Translation from "Makers of Electricity," p. 143.

number of pairs of metals, and found that when the nerve was touched by one metal and the muscle or another point on the nerve was touched by another metal and the two metals were then brought into contact or were connected through another metal or through the human body, the muscles would contract as they would when stimulated by electricity.

Galvani concluded that the contraction in this case, as in the earlier experiments, was produced by an electric stimulation, and since the metals seemed to him to serve merely as the conductors of the electric discharge, he concluded that the source of the electricity must be in the tissues of the animal body. This seemed all the more probable since it was known that certain fishes and an electric eel were capable of giving violent electric shocks. This electricity of the eels and fishes had been named animal electricity, and Galvani concluded that all animals were capable of producing this electricity in the tissues of their bodies.

He believed this electricity was to be found in various parts of the body, but that it was especially collected in the nerves and muscles. The especial property of this animal electricity seemed to be that it discharged from the nerves into the muscles, or in the contrary direction, and that to effect this discharge it would take the path of least resistance through the metal conductor or through the human body. Since during this discharge the muscle was caused to contract, Galvani concluded that the purpose of this animal electricity was to produce muscular contractions.

Galvani seems to have concerned himself principally with the physiological processes which he believed gave rise to the electric charges, but physicists began immediately to seek for other sources of the electricity. The one observation which seemed to offer a definite suggestion as to the possible source of the electrical charge was the fact that, in general, two different metals must be used to connect the muscle and nerve before a discharge would take place from the one to the other. This made Galvani's theory that the metals served merely as conductors seem improbable. On the other hand, it was sometimes possible to get the muscular contractions by using a single bent wire or rod to connect the nerve and muscle, especially if the two ends were of different degrees of polish, or if one end was warmer than the other.

Volta was apparently the first to suggest that the electricity which seemed to be generated in Galvani's experiments might have its source in the contact of the two metals. Several writers called attention to an apparent relation between Galvani's experiments and a phenomenon announced by J. G. Sulzer, in 1760. Sulzer found that if pieces of lead and silver were placed upon the tongue separately no marked taste was produced by either, but that if while both were on the tongue the metals were brought into contact a strong taste was produced which he compared to the taste of iron vitriol. Here was a case of undoubted stimu-

lation of the nerves of taste by the contact of two metals, and it seemed not improbable that other nerves might be stimulated in the same manner. In the meantime Mr. John Robison had increased the Sulzer effect greatly by building up a pile of pieces of zinc with silver shillings and placing these in contact with the tongue and the cheek.

It was the question as to the possibility of producing the electric charge by mere metallic contact which led Cavallo to make his experiments upon contact electrification. Thus Cavallo says in Volume III. of "A Complete Treatise on Electricity," published in 1795:

The above mentioned singular properties, together with some other facts, which will be mentioned in the sequel, induced Mr. Volta, to suspect that possibly in many cases the motions are occasioned by a small quantity of electricity produced by the mere contact of two different metals; though he acknowledges that he by no means comprehends in what manner this can happen. This suspicion being entertained by so eminent a philosopher as Mr. Volta, induced Dr. Lind and myself to attempt some experiment which might verify it; and with this in view we connected together a variety of metallic substances in diverse quantities, and that by means of insulated or not insulated communications; we used Mr. Volta's condenser, and likewise a condenser of a new sort; the electrometer employed was of the most sensible sort; and various other contrivances were used, which it will be needless to describe in this place; but we could never obtain the smallest appearance of electricity from those metallic combinations. Yet we can infer to no other conclusion, but that if the mere combination, or contact, of the two metals produces any electricity, the quantity of it in our experiments was too small to be manifested by our instruments.

Later, on page 111 of the same volume, he says:

After many fruitless attempts, and after having sent to the press the preceding part of this volume, I at last hit upon a method of producing electricity by the action of metallic substances upon one another, and apparently without the interference of electric bodies. I say apparently so, because the air seems to be in a great measure concerned in those experiments, and perhaps the whole effect may be produced by that surrounding medium. But, though the irregular, contradictory, and unaccountable effects observed in these experiments do not as yet furnish any satisfactory theory, and though much is to be attributed to the circumambient air, yet the metallic substances themselves seem to be endowed with properties peculiar to each of them, and it is principally in consequence of those properties that the produced electricity is sometimes positive, at other times negative, and various in its intensity.

Cavallo then proceeds to describe the experiments on contact electrification which were described in the previous paper referred to at the beginning of the article.

Cavallo's experiments were evidently made in 1795. In the following year Volta announced the discovery of the electrical current. In a letter written to Gren's *Neues Journal der Physik*, August, 1796, Volta says:

The contact of different conductors, particularly the metallic, including pyrites and other minerals as well as charcoal, which I call dry conductors, or

of the *first class* with moist conductors, or conductors of the *second class*, agitates or disturbs the electric fluid, or gives it a certain impulse. Do not ask in what manner: it is enough that it is a principle and a great principle.

It will be seen that at this stage of his discovery Volta was inclined to attribute the origin of the current to the contact between the metals and his moist "conductors of the second class," though later in the same article he says it is impossible to tell whether the impulse which sets the current in motion is to be attributed to the contact between the metals themselves or between the two metals and the moist conductor, since either supposition would lead to the same results.

Later, as was shown in the previous paper by the present writer, Volta came to regard the metallic contact as the cause of the electromotive force. In a letter written to Gren in 1797 and published as a postscript to his letter of August, 1796, Volta says:

Some new facts, lately discovered, seem to show that the immediate cause which excites the electric fluid, and puts it in motion, whether it be an attraction or a repulsive power, is to be ascribed much rather to the mutual contact of two different metals, than to their contact with moist conductors.

The new facts, "lately discovered," to which Volta attributes his change of view were his repetitions of Bennett's experiments of 1789.

Volta apparently thought that the current was not only set up by the contact of the two metals of a pair, but that it was kept up by the mutual action of the metals on each other. He accordingly made no attempt to discover whether any changes took place in his circuit while the current was being generated. The chemical action on his metals and the dissociation in his electrolyte seem to have entirely escaped his attention. At least, he did not attach enough importance to them to mention them anywhere in his description of his apparatus.

In the meantime a chemical explanation of the phenomena observed by Galvani had been proposed in 1792 by Fabroni, a physicist of Florence. After discussing the Sulzer phenomenon already mentioned in this paper, Fabroni argues that the peculiar taste caused by bringing the two metals into contact while on the tongue is due to a chemical, rather than to an electrical, action. He then discusses the different chemical behavior of metals when taken singly and when placed in contact with other metals. He says:²

I have already frequently observed that fluid mercury retains its beautiful metallic luster for a long time when by itself; but as soon as it is amalgamated with any other metal it becomes rapidly dim or oxidized, and in consequence of its continuous oxidation increases in weight.

I have preserved pure tin for many years without its changing its silvery luster, while different alloys of this metal which I have prepared for technical purposes have behaved quite otherwise.

² The following quotations from Fabroni have been translated by the present writer from the German of Ostwald's "Elektrochemie," pp. 103, ff.

I have seen in the museum at Cortonne Etruscan inscriptions upon plates of pure lead which are perfectly preserved to this day, although they date from very ancient times; on the other hand, I have found with astonishment in the gallery of Florence that the so-called "piombi" or leaden medallions of different popes, in which tin and possibly some arsenic have been mixed to make them harder and more beautiful, have fallen completely to white powder, or have changed to their oxides, though they were wrapped in paper and preserved in drawers.

In the same way I have observed that the alloy which was used for soldering the copper plates upon the movable roof of the observatory at Florence has changed rapidly and in places of contact with the copper plates has gone over into a white oxide.

I have heard also in England that the iron nails which were formerly used for fastening the copper plates of the sheathing of ships were attacked on account of contact, and that the holes became enlarged until they would slip over the heads of the nails which held them in position.

It seems to me that this is sufficient to show that the metals in these cases exert a mutual influence upon each other, and that to this must be ascribed the cause of the phenomena which they show by their combination or contact.

After discussing some of the experiments on nerve stimulation which had been made by Galvani and others, Fabroni argues that these are principally, if not wholly, due to chemical action, and that the undoubted electrical phenomena which sometimes accompany them are not the cause of the muscular contractions.

In discussing the nature of the chemical changes produced in two metals by their mutual contact, Fabroni says:

Since the metals have relationships with each other, the molecules must mutually attract each other as soon as they come into contact. One can not determine the force of this attraction, but I believe it is sufficient to weaken their cohesion so that they become inclined to go into new combinations and to more easily yield to the influence of the weakest solvents.

In order to further show the weakening of cohesion by the contact of two metals, Fabroni describes the results of some experiments which he has made. He says:

In order to assure myself of the truth of my assumptions, I put into different vessels filled with water:

(1) Separate pieces, for example, of gold in one, silver in another, copper in the third, likewise tin, lead, etc.

(2) In other similar vessels I put pieces of the same metals in pairs, a more oxidizable and a less oxidizable metal in each pair, but separated from each other by strips of glass.

(3) Finally, I put in other vessels pairs of different metals which were placed in immediate contact with each other.

The first two series suffered no marked change, while in the latter series the more oxidizable metal became visibly covered with oxide in a few instants after the contact was made.

Fabroni found that under the above circumstances his oxidizable metals dissolved in the water, and in some cases salts were formed which

crystallized out. He then compares the metals in contact with each other in water with the metals on the tongue when brought into contact, as in Sulzer's experiment, and the two metals touching each other by which different points on a nerve were touched to produce the muscular twitchings in Galvani's experiments, and concludes that the chemical action upon the metals was the same in each case, and that the other phenomena observed must have resulted from this chemical action. It is not strange that when Volta showed later that an electric current passed between the metals in all of the above cases Fabroni should regard the chemical action which he had previously observed as the cause of this current.

Ten years after the publication of Fabroni's original paper, Volta wrote a letter to J. C. Delamethrie which was published in Vol. I of *Nicholson's Journal*. This letter was written after the chemical changes in the voltaic cell had received a great deal of attention by many experimenters, the most prominent of whom was Davy. To show that Volta's theory as to the source of the current was not affected by these investigations, a quotation from this letter is given below.

You have requested me to give you an account of the experiments by which I demonstrate, in a convincing manner, what I have always maintained, namely, that the pretended agent, or *galvanic fluid*, is nothing but common electrical fluid, and that this fluid is incited and moved by the simple *mutual contact of different conductors*, particularly the metallic; shewing that two metals of different kinds, connected together, produce already a small quantity of true electricity, the force and kind of which I have determined; that the effects of my new apparatus (which might be termed electromotors), whether consisting of a pile, or in a row of glasses, which have so much excited the attention of philosophers, chemists, and physicians; that these so powerful and marvelous effects are absolutely no more than the sum total of the effects of a series of several similar metallic couples or pairs; and that the chemical phenomena themselves, which are obtained by them, of the decomposition of water and other liquids, the oxidation of metals, &c., are secondary effects; effects, I mean, of this electricity, of this continual current of electrical fluid, which by the above mentioned action of the connected metals, establishes itself as soon as we form a communication between the two extremities of the apparatus, by means of a conducting bow; and when once established, maintains itself, and continues as long as the circuit remains interrupted.³

Further along in the same letter Volta reiterates his conviction that the contact of the two metals furnishes the true motive power of the current. Thus he says (p. 138):

As to the rest, the action which excites and gives motion to the electric fluid does not exert itself, as has been erroneously thought, at the contact of the wet substance with the metal, where it exerts so very small an action, that it may be disregarded in comparison with that which takes place, as all my experiments prove, at the place of contact of different metals with each other. Consequently the true element of my electromotive apparatus, of the pile, of

³ This seems to be a misprint for uninterrupted.

cups, and others that may be constructed according to the same principles, is the simple metallic couple, or pair, composed of two different metals, and not a moist substance applied to a metallic one, or inclosed between two different metals, as most philosophers have pretended. The humid strata employed in these complicated apparatus are applied therefore for no other purpose than to effect a mutual communication between all the metallic pairs, each to each, ranged in such a manner as to impel the electric fluid in one direction, or in order to make them communicate, so that there may be no action in a direction contrary to the others.

At the end of the above letter as published in *Nicholson's Journal*, the editor, William Nicholson, comments at length on Volta's theory of the source of current in the cell and calls attention to the fact that Davy had already made cells by the use of a single metal and two different liquids. At the conclusion of his comments he call attention to the fact that Bennett and Cavallo had performed experiments with contact electrification prior to Volta's experiments, and says in conclusion, after referring to Bennett,

This last philosopher, as well as Cavallo, appears to think that different bodies have different attractions or capacities for electricity; but the singular hypothesis of electromotion, or a perpetual current of electricity being produced, by the contact of two metals is, I apprehend, peculiar to Volta.

This peculiar theory of Volta's probably never gained many adherents and was necessarily abandoned as soon as the energy relations of the current were considered, but the controversy as to whether the electrical current or the accompanying chemical changes was the primary phenomenon soon became transferred to a quite different field, viz., to the origin of the electrical charges which Bennett had shown resulted from the contact of different metals. Bennett attempted to account for the phenomena which he had observed on the hypothesis that different substances "have a greater or less affinity with the electric fluid," and Cavallo says:

I am inclined to suspect that different bodies have different capacities for holding the electric fluid.

Volta reaches a similar conclusion after repeating some of Bennett's experiments. In referring to this decision of Volta as to the origin of the electric charge in contact electrification, Ostwald says:

We stand here at a point where the most prolific error of Electrochemistry begins, the combating of which has from that time on occupied almost the greater part of the scientific work in this field.

The error, from Ostwald's point of view, lies in the assumption that the transference of electricity from the one metal to the other is a primary phenomenon of metallic contact. He, with many others, including some of the most distinguished physicists and chemists of the past century, regard the electrical transference as a secondary phe-

nomenon resulting from the previous oxidation of one of the metals. Thus Lodge, in discussing the opposite electrification of plates of zinc and copper when brought into contact says:

The effective cause of the whole phenomenon in either case is the greater affinity of oxygen for zinc rather than copper.

The apparent conflict of opinion between those who hold that the different affinities of the metals for oxygen is the cause of the rearrangement of their electrical charges when brought into contact and those who hold with Bennett and Cavallo that the metals in their natural state have different affinities for the electrical fluid must disappear when we recognize that all affinity, and consequently the affinity for oxygen, must be an electrical attraction. If zinc has an affinity for oxygen, it must be because the zinc is either electropositive or electronegative to oxygen. If it has a greater affinity for oxygen than copper has, then the zinc must be either electropositive or electronegative to copper. This being the case, and both being conductors, it is not surprising that some electricity will flow from one to the other when the two metals are brought into contact.

Those writers who attribute the oxidation theory of contact electrification to Fabroni apparently overlook the fact that not oxidation, but the weakening of the cohesion of at least one of the metals due to their contact, was the primary phenomenon in Fabroni's theory. When this is remembered, it is seen that the observations of Bennett and Fabroni, instead of furnishing arguments for two conflicting theories, actually serve, as all true scientific observations must, to supplement each other.

Thus we now know that cohesion or affinity is an electrical attraction between the atoms or molecules of a body. The only known methods of changing the electrical attraction between two bodies whose distances and directions from other bodies remain constant is by varying the magnitude of their charges or by changing the specific inductive capacity of the medium between them. Bennett observed that when two pieces of different metal in their normal electrical condition are placed in contact, there is a redistribution of the charges of their surface atoms. Fabroni observed under the same conditions a change in the surface cohesion of the two metals.

To the present writer this seems the actual sequence of phenomena, viz., a redistribution of the charges of the surface atoms of the metals, a consequent change in surface cohesion and a resultant oxidation of one of the metals.